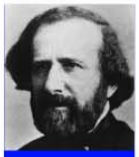


HISTORY of Stellar Interferometry

Optical Interferometry Motivation and History

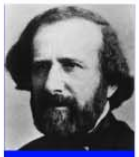
Peter Lawson

Jet Propulsion Laboratory

4800 Oak Grove Drive
Pasadena, CA 91109

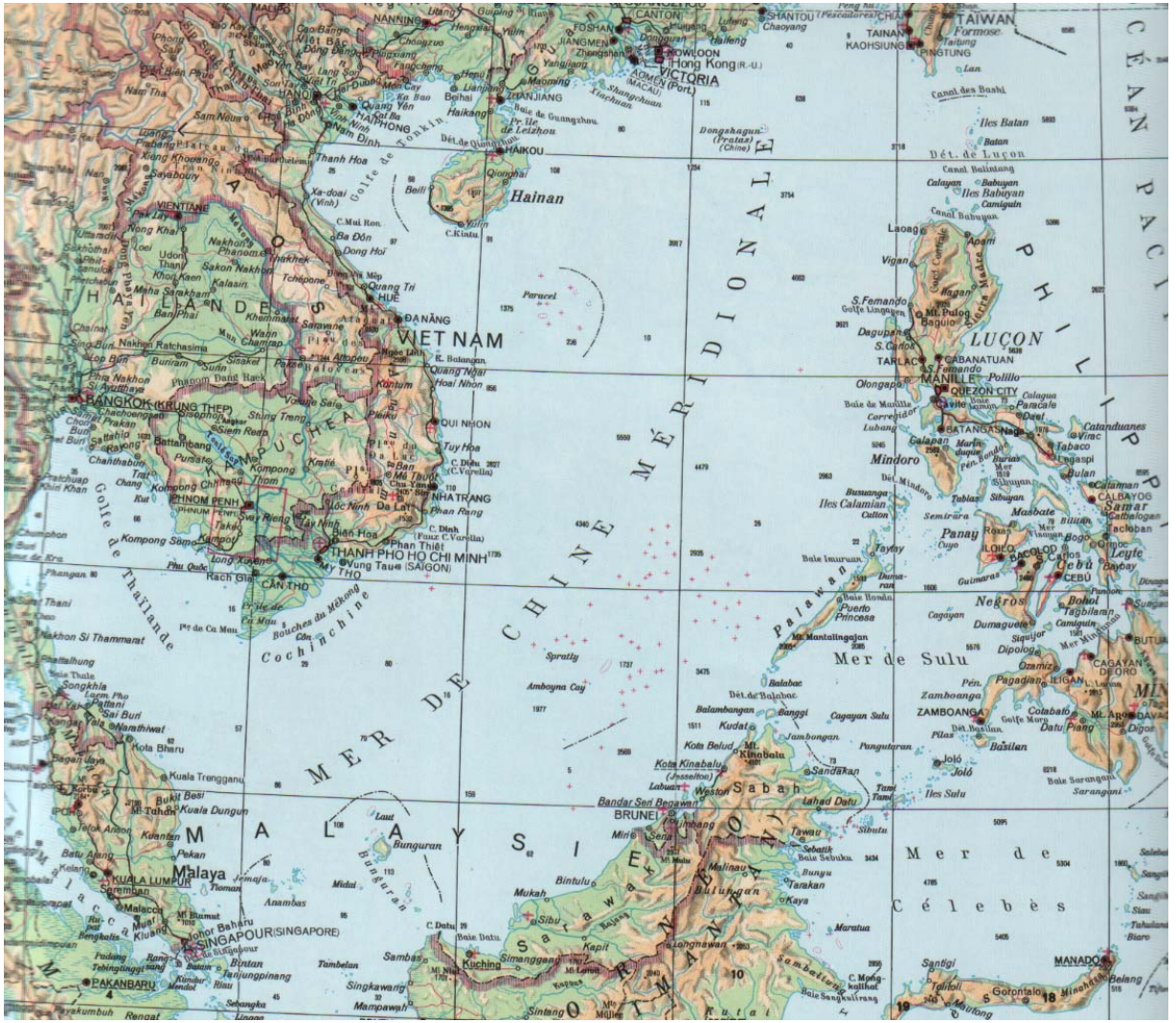
2006 Michelson Summer Workshop
Pasadena, California, 24 July 2006

On Tides, Organ Pipes, and Soap Bubbles

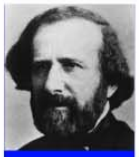


HISTORY of Stellar Interferometry

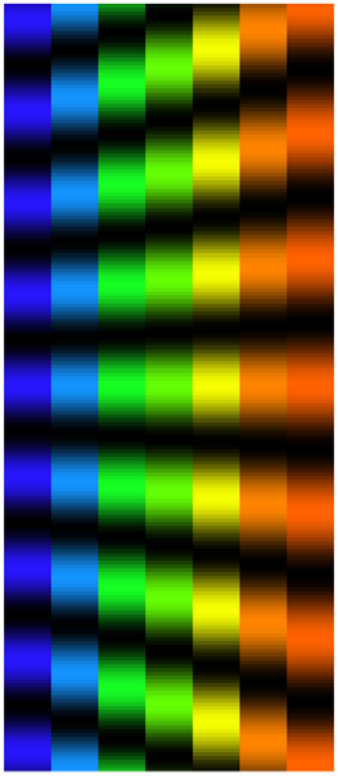
- Tides at Batsha (1684)
- Newton's *Principia* (1688)
- Thomas Young (1773-1829) and uncle Brocklesby
- General Law of interference
- Two slit experiment (1802)



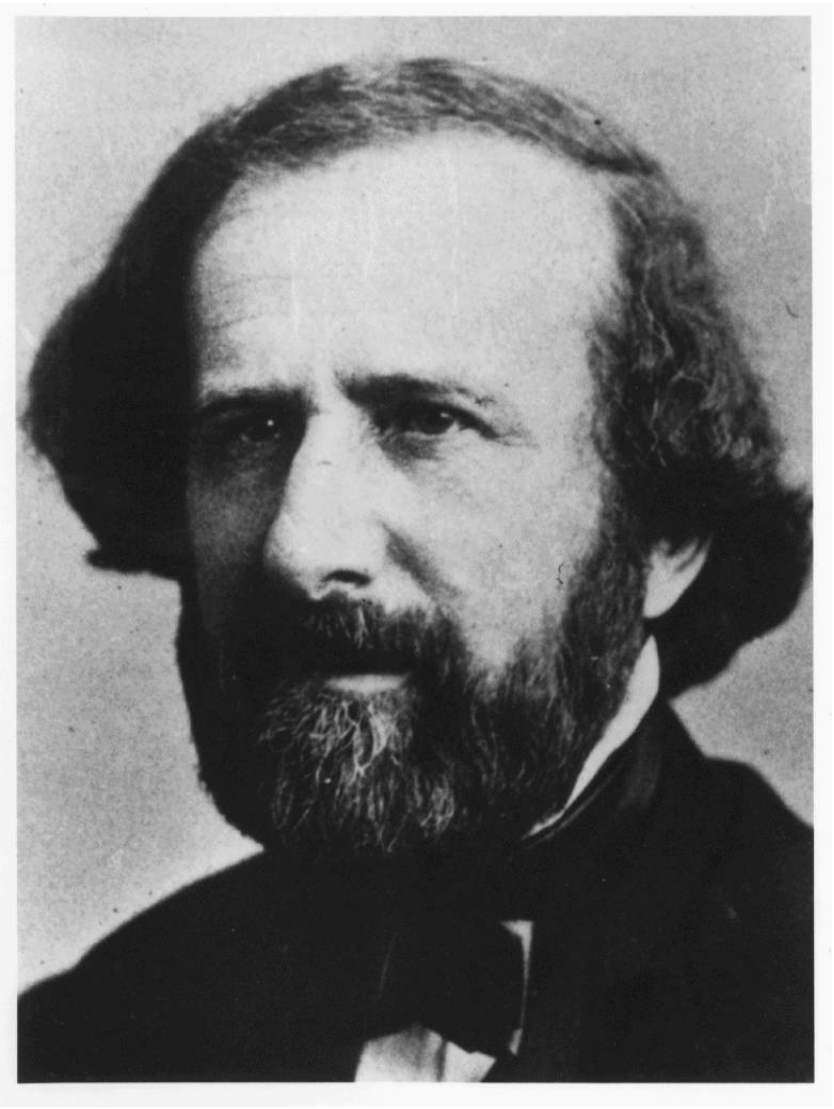
Armand Hippolyte Fizeau (1819-1896)



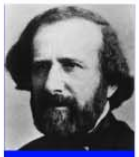
HISTORY of Stellar Interferometry



- 1845 Fizeau and Foucault describe fringes in dispersed light



Fizeau Suggests Stellar Interferometry 1867



HISTORY of Stellar Interferometry

PRIX BORDIN.

QUESTION PROPOSÉE EN 1865 POUR 1867.

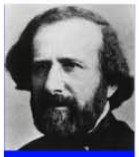
(Commissaires : MM. Duhamel, Pouillet, Regnault, Bertrand, Edmond Becquerel, Fizeau rapporteur.)

Rapport sur le Concours de l'année 1867.

« *Le prix sera décerné au savant qui aura exécuté ou proposé une expérience* » *décisive permettant de trancher définitivement la question déjà plusieurs fois* » *étudiée de la direction des vibrations de l'éther dans les rayons polarisés.* »

Il existe en effet pour la plupart des phénomènes d'interférence, tels que les franges d'Yung, celles des miroirs de Fresnel et celles qui donnent lieu à la scintillation des étoiles d'après Arago, une relation remarquable et nécessaire entre la dimension des franges et celle de la source lumineuse, en sorte que des franges d'une ténuité extrême ne peuvent prendre naissance que lorsque la source de lumière n'a plus que des dimensions angulaires presque insensibles; d'où, pour le dire en passant, il est peut-être permis d'espérer qu'en s'appuyant sur ce principe et en formant par exemple, au moyen de deux larges fentes très-écartées, des franges d'interférence au foyer des grands instruments destinés à observer les étoiles, il deviendra possible d'obtenir quelques données nouvelles sur les diamètres angulaires de ces astres.

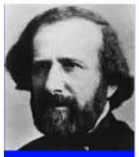
Edouard Stephan (1837-1923)



HISTORY of Stellar Interferometry

- 1874 E. Stephan uses the Foucault refractor at the Marseilles Observatory to observe most stars down to 4th magnitude.
  - 65 cm aperture separation.
  - All stars produce distinct fringes.
  - Concludes stars must have diameters much smaller than 0.158 arcseconds.

Foucault Refractor



HISTORY of Stellar Interferometry

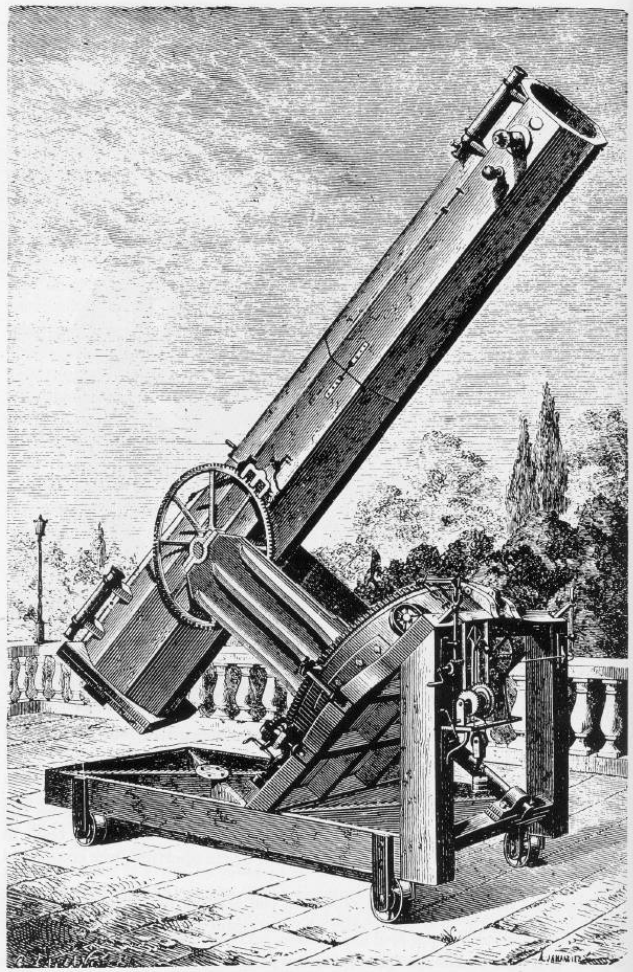
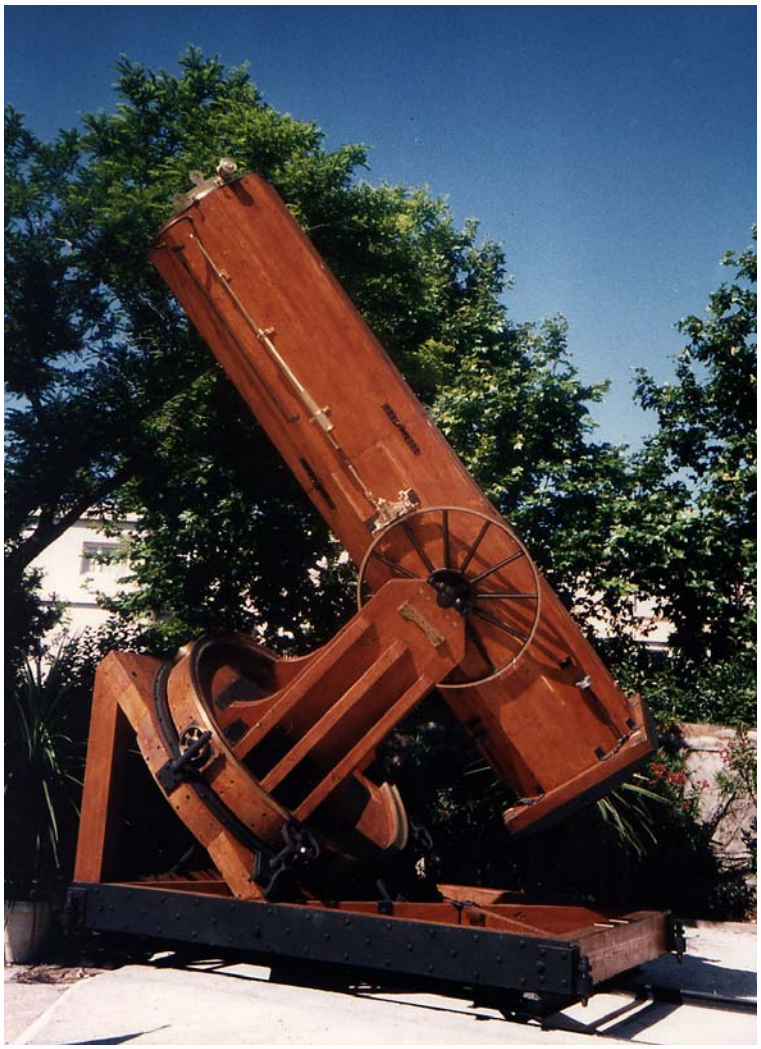
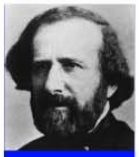


Fig. 5.8. Foucault's largest (80 cm) silver-on-glass reflector, completed in 1862 (reproduced from King [5.2])



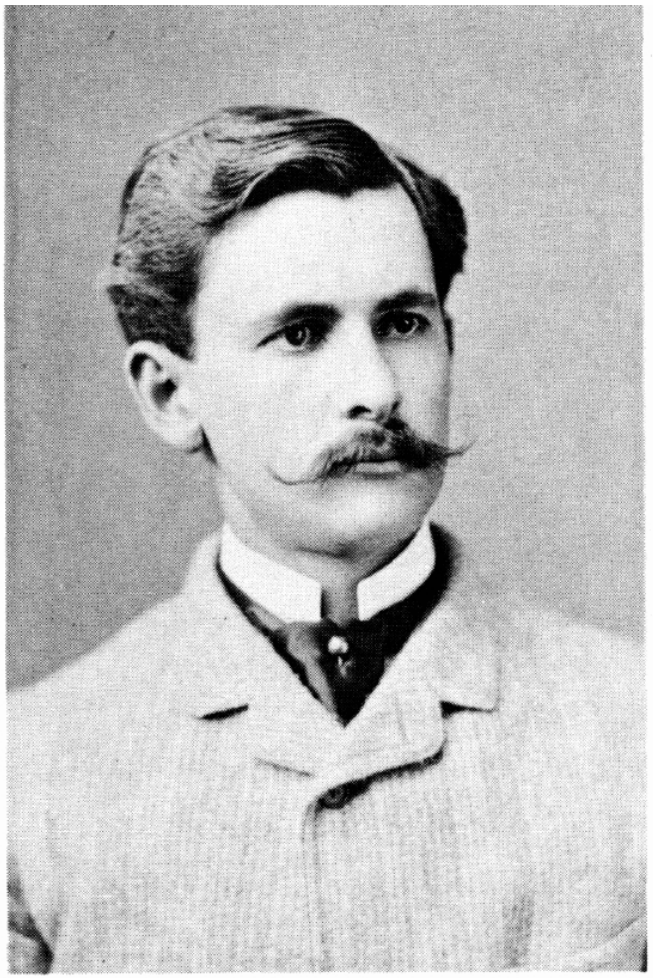
Albert A. Michelson (1852-1931)



HISTORY of Stellar Interferometry

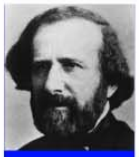
- 1878. Measures speed of light 200 times more accurately than previous measurements.
- 1880. Invents *Interferential Refractometer* in Berlin while on leave from Naval Academy.
- 1887. Michelson-Morley experiment.
- 1890. Describes mathematical basis of stellar interferometry

...and proposes an approach to long-baseline optical interferometry

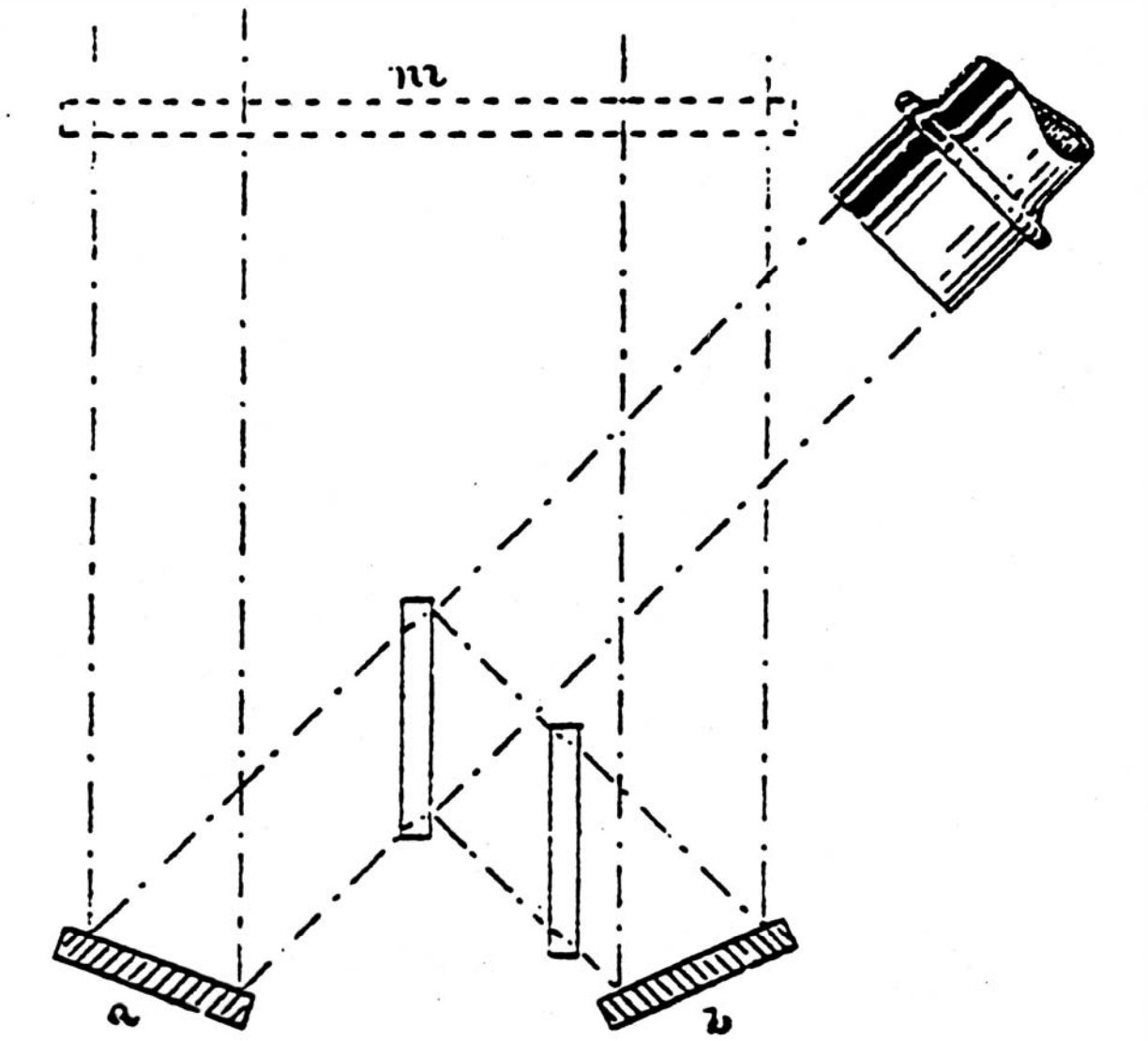


Michelson in 1887, at the time of the Michelson-Morley experiment
(COURTESY CLARK UNIVERSITY ARCHIVES)

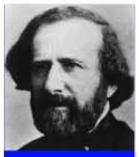
On the Application of Interference Methods to Astronomy (1890)



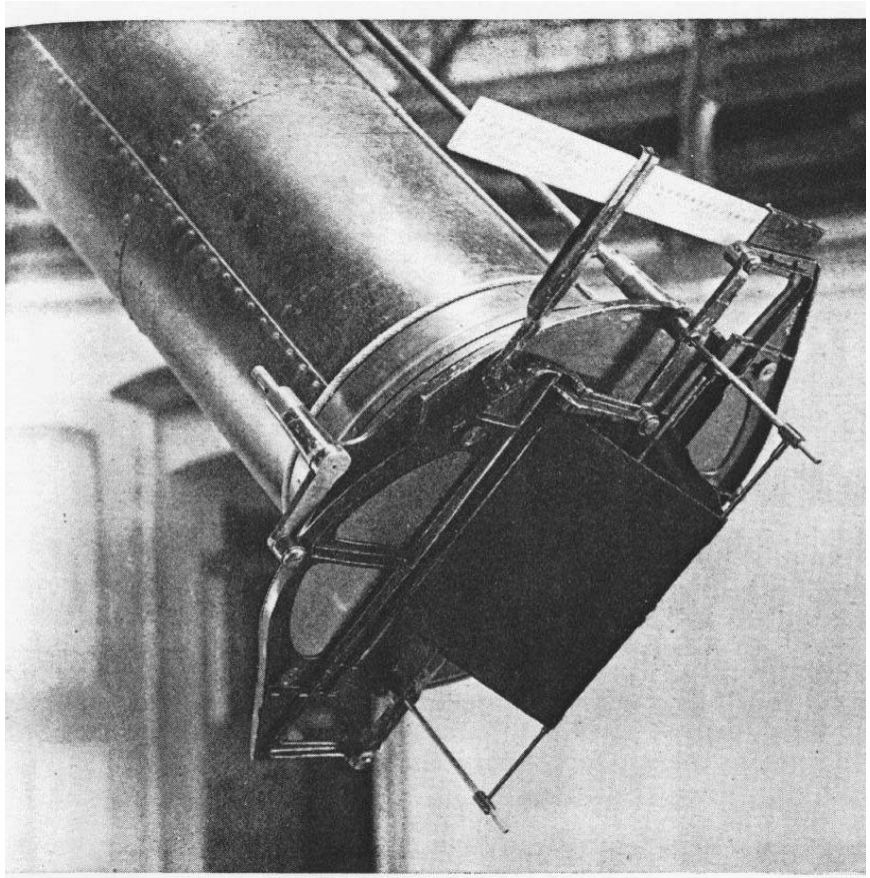
HISTORY of Stellar Interferometry



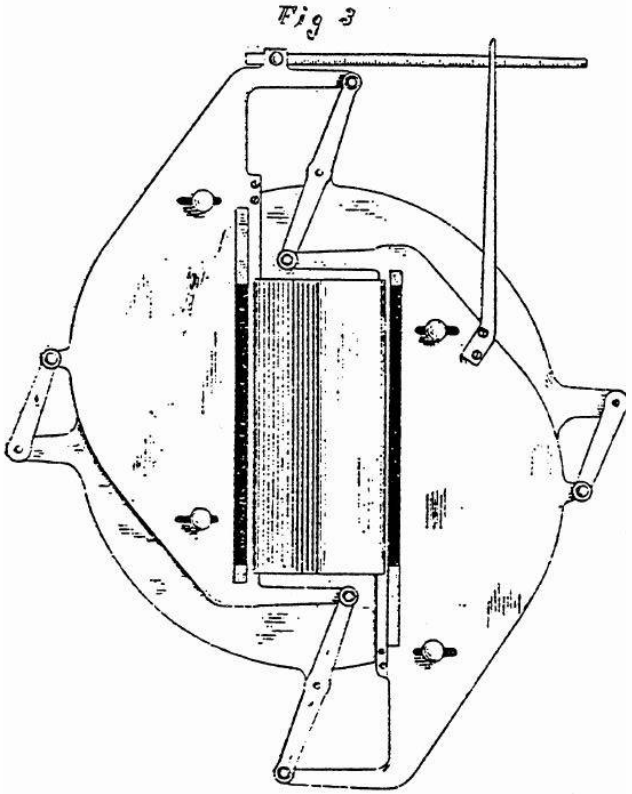
Moons of Jupiter (1891)



HISTORY of Stellar Interferometry



Interferometric mask used on the 12-inch refractor at Lick Observatory to measur the angular diameters of the Jovian satellites. The rod adjacent to the telescop tube is turned by the observer, which in turn rotates a lever connecting the tw slits immediately exterior to the pictured objective shroud. Photograph courtes University of California at Santa Cruz Library.

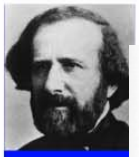


With this apparatus the satellites of Jupiter were measure ith results as given in the following table :—

TABLE I.

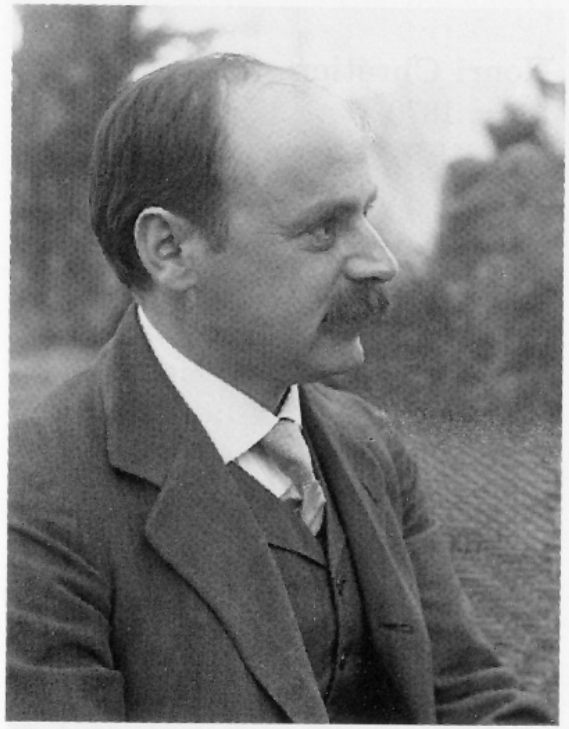
No. of Satellites.	I.	II.	III.	IV.	Seeing.
August 2 ...	1″29	1″19	1″88	1″68	Poor.
August 3 ...	1·29	—	1·59	1·68	Poor.
August 6 ...	1·30	1·21	1·69	1·56	Poor.
August 7 ...	1·30	1·18	1·77	1·71	Good.
Mean...	1·29	1·19	1·73	1·66	

Other Applications in 19th Century

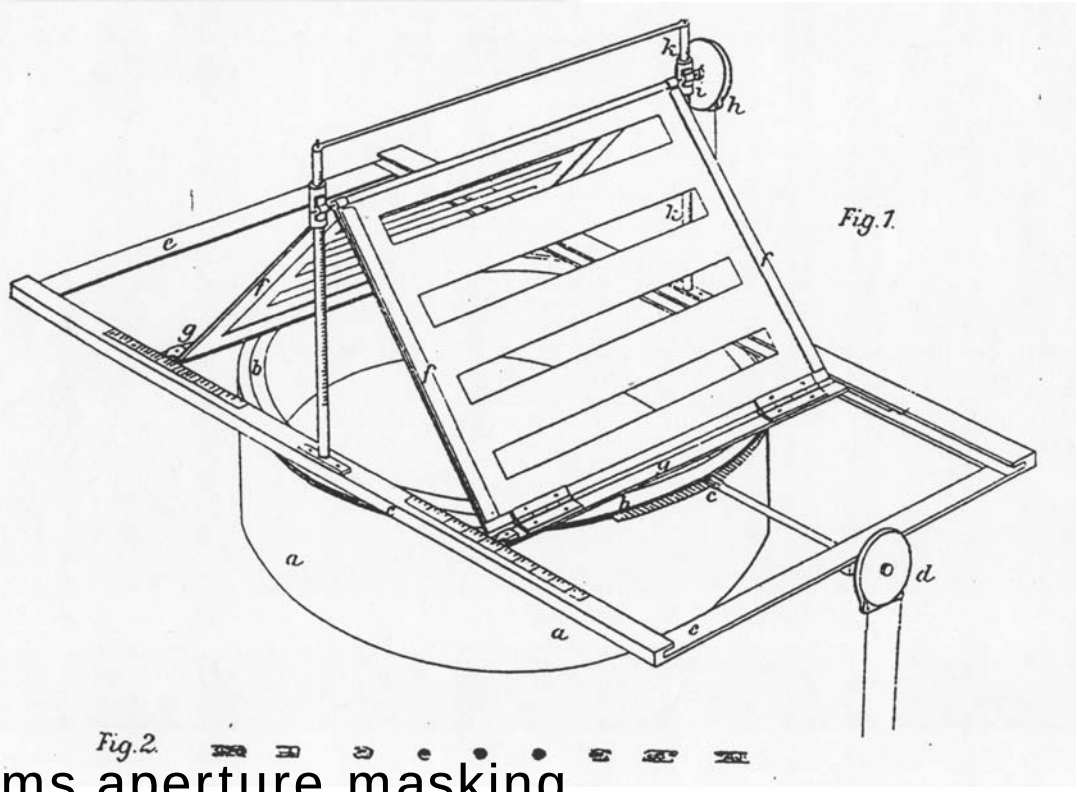


HISTORY of Stellar Interferometry

- First use of interferometry to measure binary stars (1895)

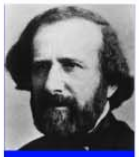


Karl Schwarzschild
Born: 1873, Frankfurt/Main,

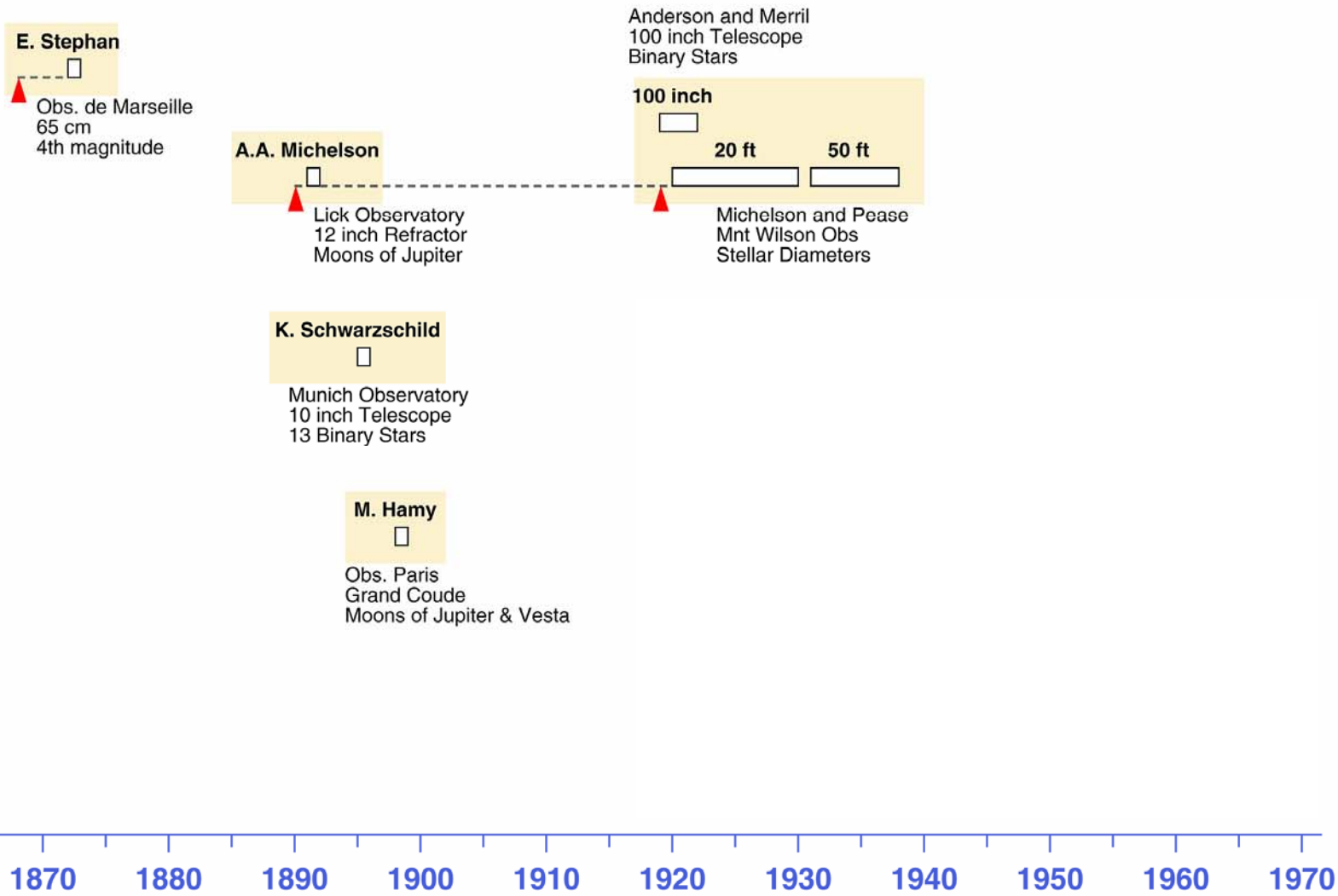


- 1896 M. Hamy performs aperture masking measurements at the Observatoire de Paris, repeating work by Michelson

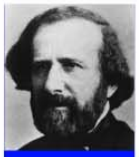
Timeline of Interferometry to 1938



HISTORY of Stellar Interferometry



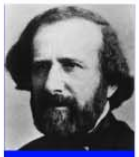
30 years goes by…



HISTORY of Stellar Interferometry

- Michelson's measurements of the Moons of Jupiter was a feasibility test. Why didn't he follow it up?
- Work had been planned with the 32-inch at Lick, but Michelson left for Europe.
- He never followed up with the observations at Lick
- Perhaps there was no point. Stars were obviously too small to measure with single telescopes
- …stellar interferometry was only a footnote in Michelson's extremely productive career
- Depression in Chicago in 1890s (little money)
- World War I

Mount Wilson Observatory



HISTORY of Stellar Interferometry

- 1914 Russell proposes two classes of red stars
- 1919 Michelson funded to measure diameters
- Much confusion over predicted sizes of stars
- 25 ft rotatable interferometer proposed to George Elliot Hale

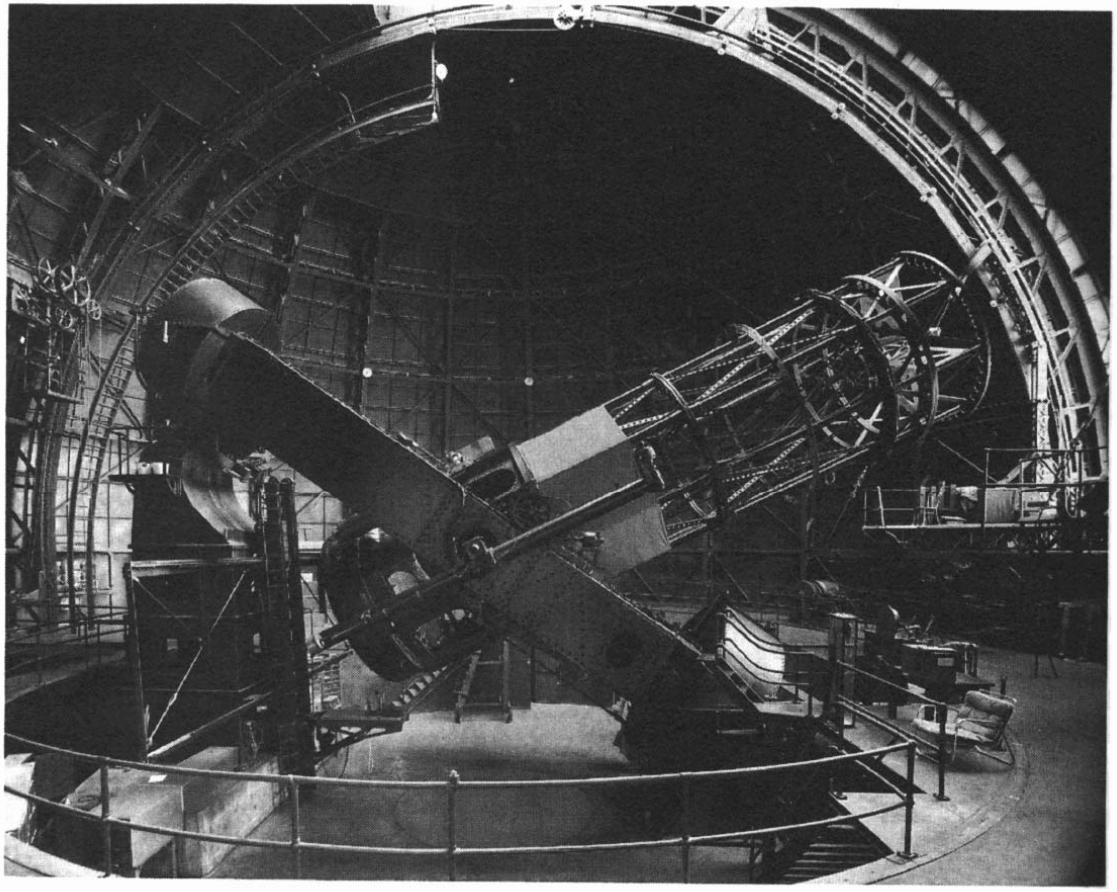
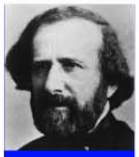


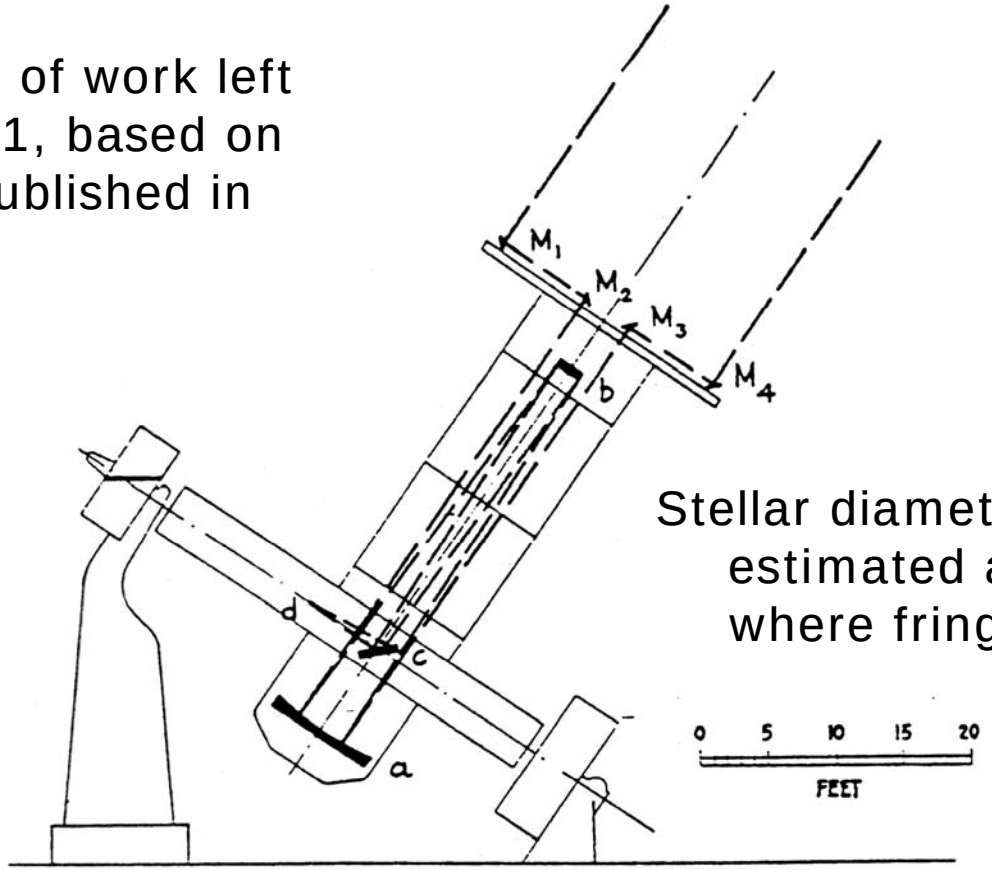
Figure 13.5 *The 100 inch (2.5 m) Hooker reflector on Mount Wilson, completed in 1917. (Courtesy* The Observatories of the Carnegie Institution of Washington.*)*

Michelson's 20 ft Interferometer



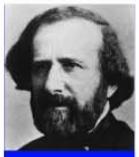
HISTORY of Stellar Interferometry

Continuation of work left off in 1891, based on an idea published in 1890



Stellar diameter estimated at baseline where fringes vanish

FIG. 1.—Diagram of optical path of interferometer pencils. M_1, M_2, M_3, M_4, mirrors; *a*, 100-inch paraboloid; *b*, convex mirror; *c*, coudé flat; *d*, focus.



HISTORY of Stellar Interferometry

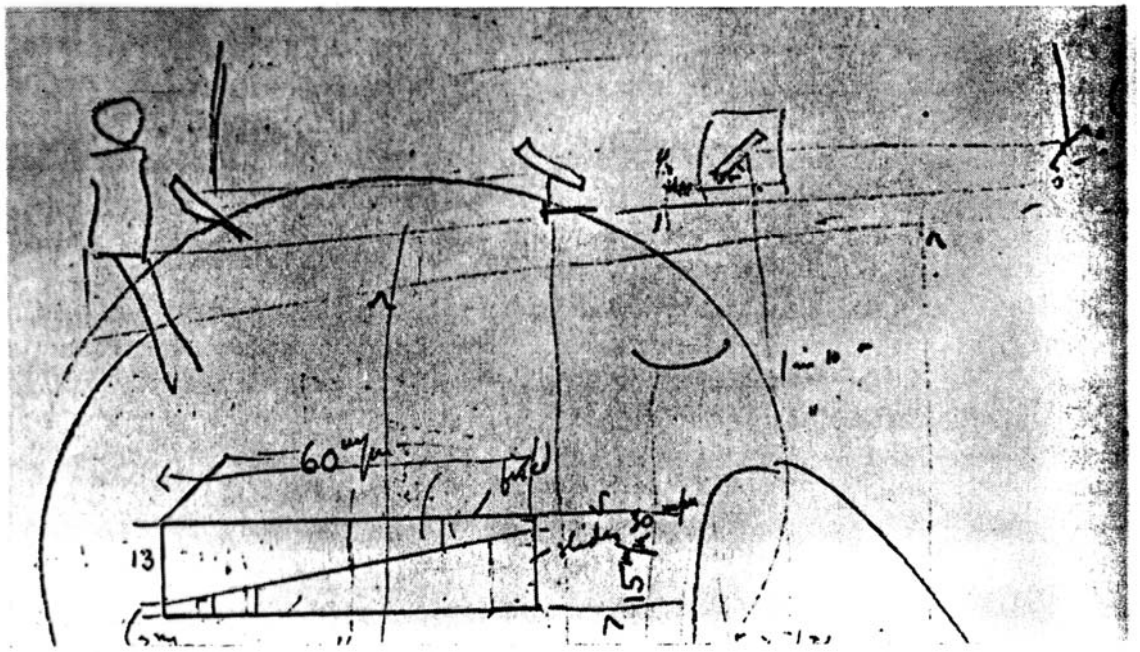


FIG. 3. From F. G. Pease, Notebook 1, sheet 42; approximate date 14 July 1920 (Hale Observatories, copy in Michelson Museum). Crude drawings of the optical wedge used to equalise path length. Note the superimposed sketch illustrating how the night assistant must be perched to move the mirrors on the beam. This situation was necessary because the mirrors, at first, were not continuously adjustable.

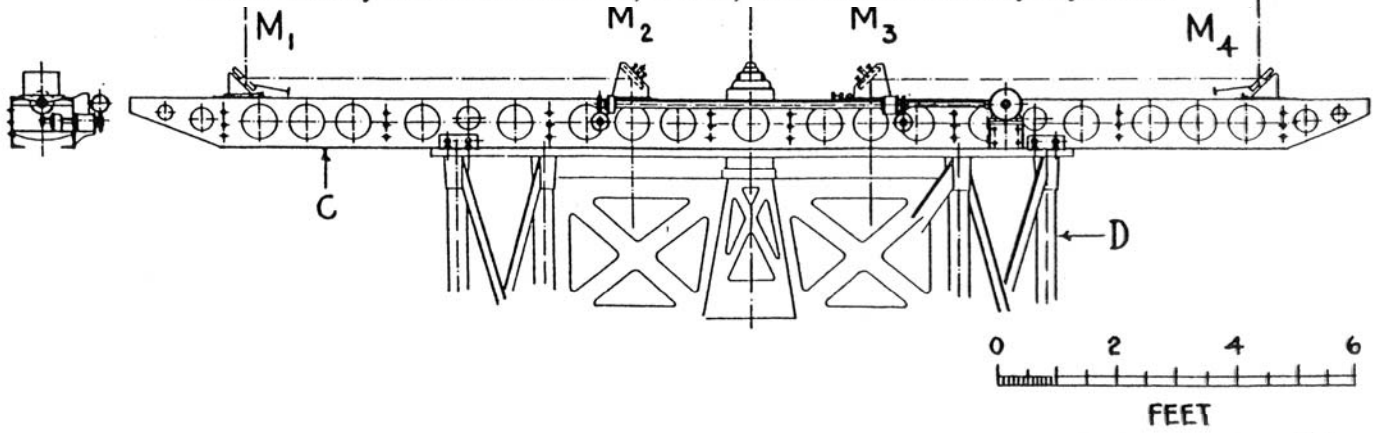
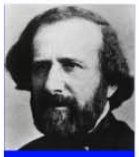


FIG. 2.—Diagram of 20-foot interferometer beam. M_1, M_2, M_3, M_4, mirrors; B, B, 10-inch channels; C, steel plate; E, E, screws to move outer mirrors; F, motor drive for screws; D, Cassegrain cage.

Was Michelson Influenced by Fizeau?



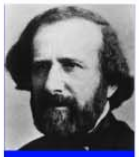
HISTORY of Stellar Interferometry

- Yes

Albert A. Michelson, about 1928

- No

...Work Continues in the 1920s and 30s



HISTORY of Stellar Interferometry

- Observations of Betelgeuse and other stars in 1921
- A small number of other targets observed in the 1920s
- Francis Pease plans a more ambitious instrument
- Michelson dies in 1931

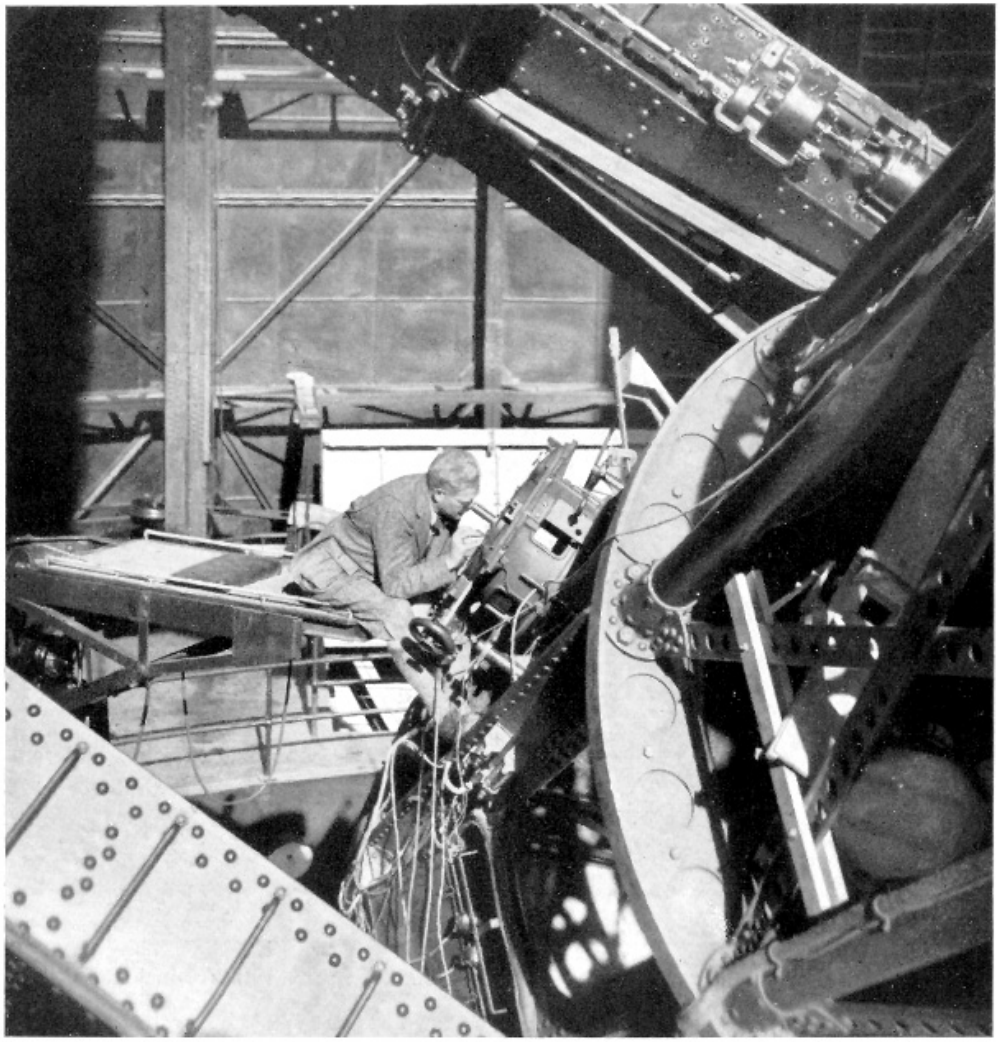
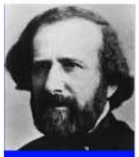


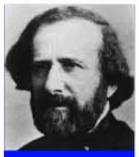
Abb. 3. Showing observer at eyepiece of 20 foot interferometer.

50 ft Interferometer (1931-1938)



HISTORY of Stellar Interferometry

Light Paths in the 50 ft Interferometer



HISTORY of Stellar Interferometry

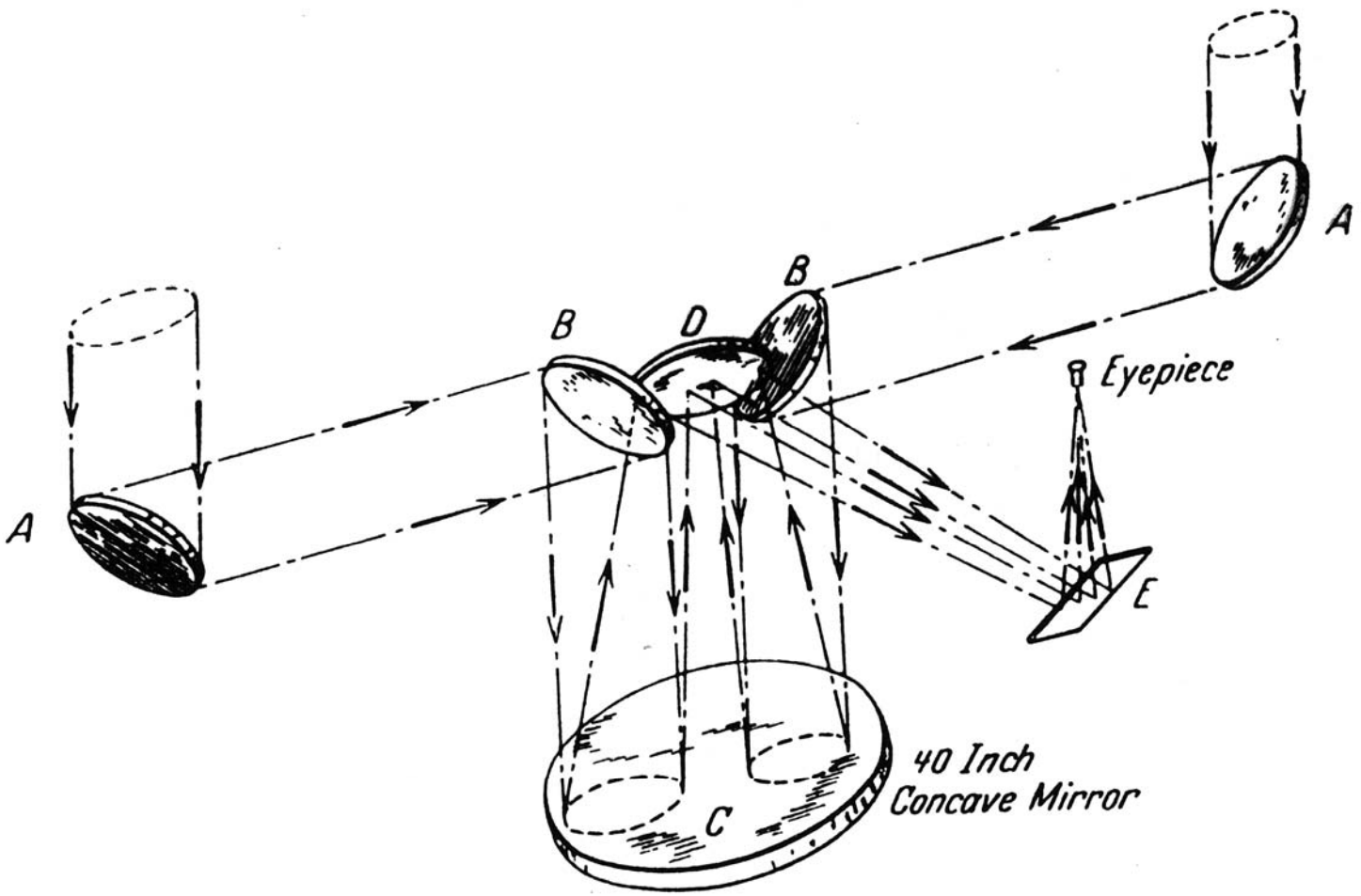
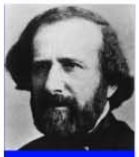


Abb. 8. Diagram of light path in 50 foot interferometer.

Ground-level at the 50 ft



HISTORY of Stellar Interferometry

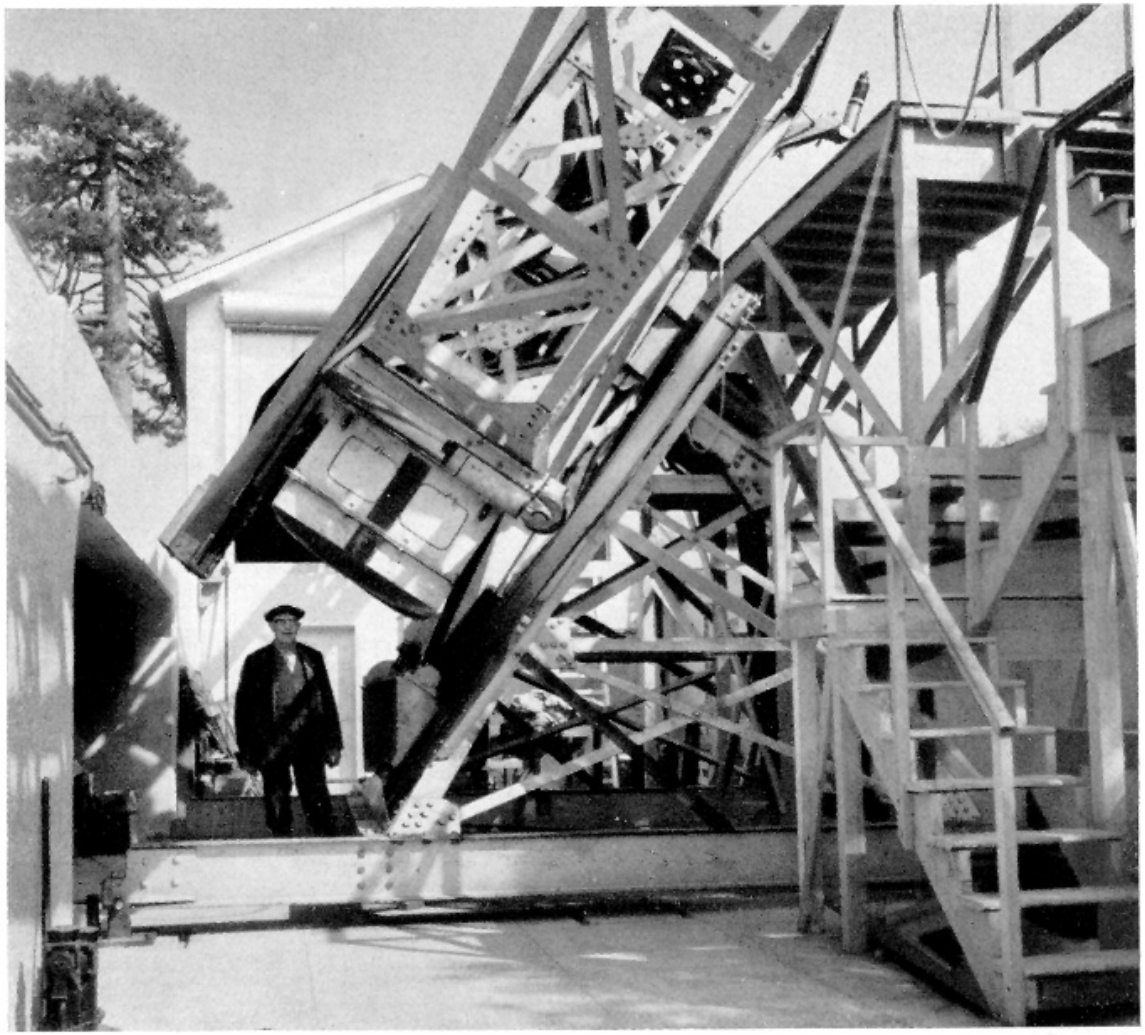
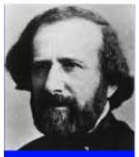


Abb. 7. The 50 foot interferometer showing pedestal, mirrorcell and wormsector.

F.G. Pease (1881-1938)



HISTORY of Stellar Interferometry

- Designed and built by F.G. Pease (1931).
- Probably subject to numerous problems
  - 38 cm mirrors produced speckled images
  - Increased fringe motion at longer baselines
  - Excessive vibrations
  - Polarization mismatch between arms
- Produced results of questionable value
  - Accuracies estimated at 10 - 20%

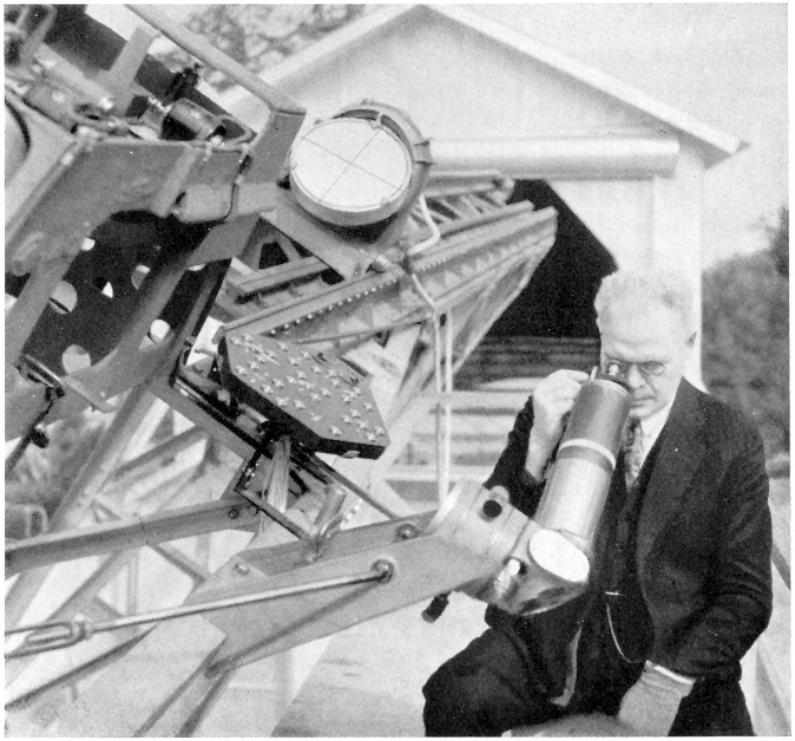
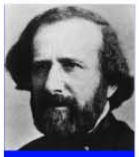


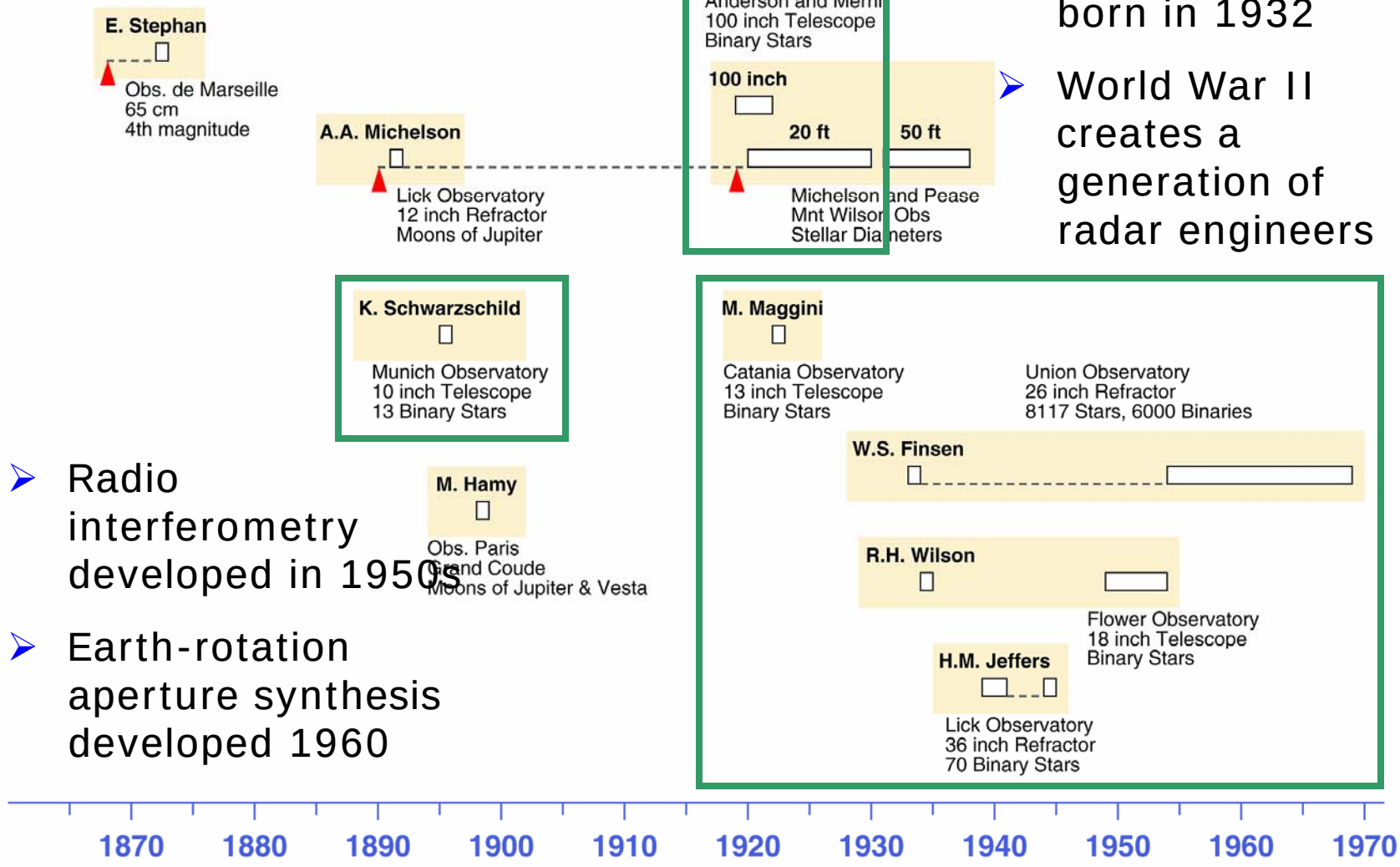
Abb. 9. Upper part of interferometer showing control board and observer at eyepiece.

- Observations ceased in 1938
- ...at the limits of technology

Timeline of Optical Interferometry to 1970

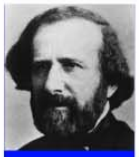


HISTORY of Stellar Interferometry

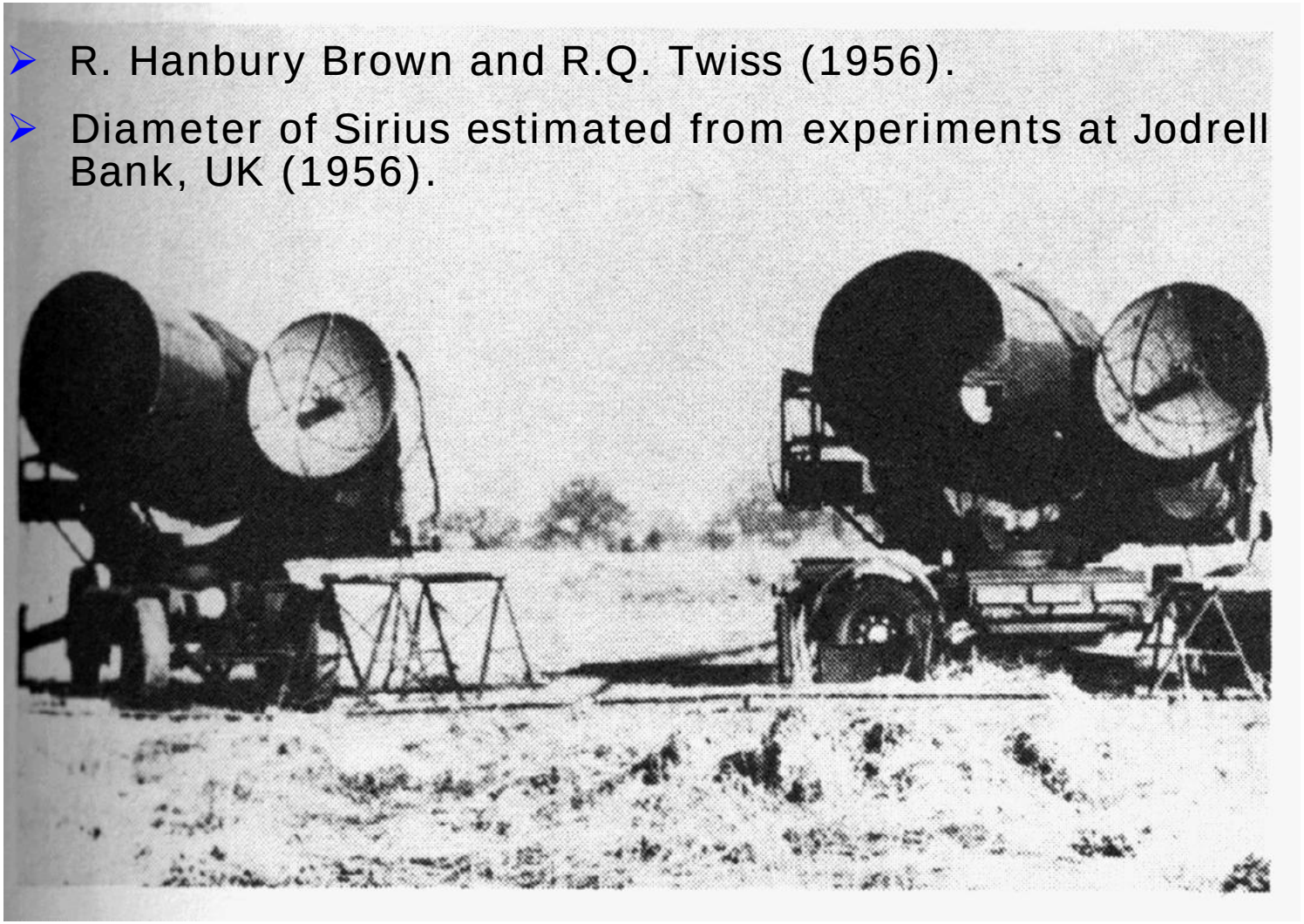


- Radio astronomy born in 1932
- World War II creates a generation of radar engineers
- Radio interferometry developed in 1950s
- Earth-rotation aperture synthesis developed 1960

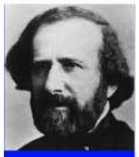
A New Type of Stellar Interferometer (1956)



- R. Hanbury Brown and R.Q. Twiss (1956).
- Diameter of Sirius estimated from experiments at Jodrell Bank, UK (1956).



Intensity Interferometer (1963-1976)



HISTORY of Stellar Interferometry

- Manchester University and Sydney University build the *Intensity Interferometer* at Narrabri, NSW, Australia (starting 1961)
  - Initially under the guidance of Twiss
  - Hanbury Brown established as Professor at Sydney University

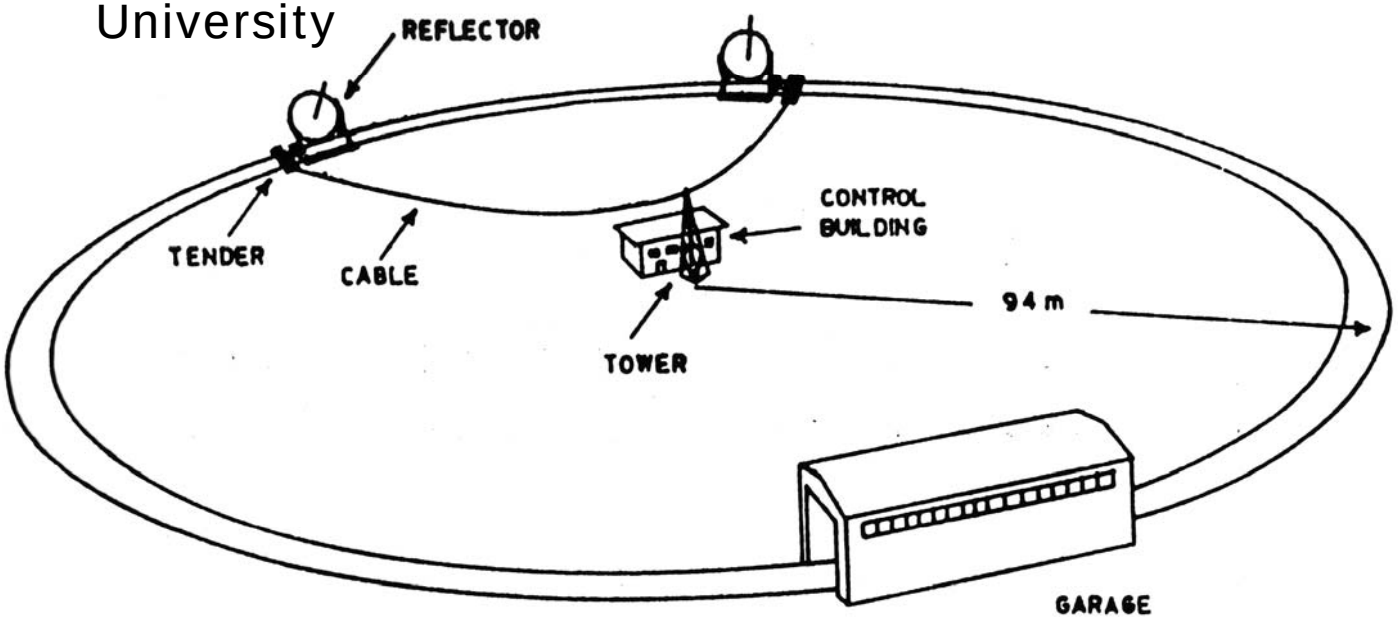
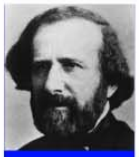


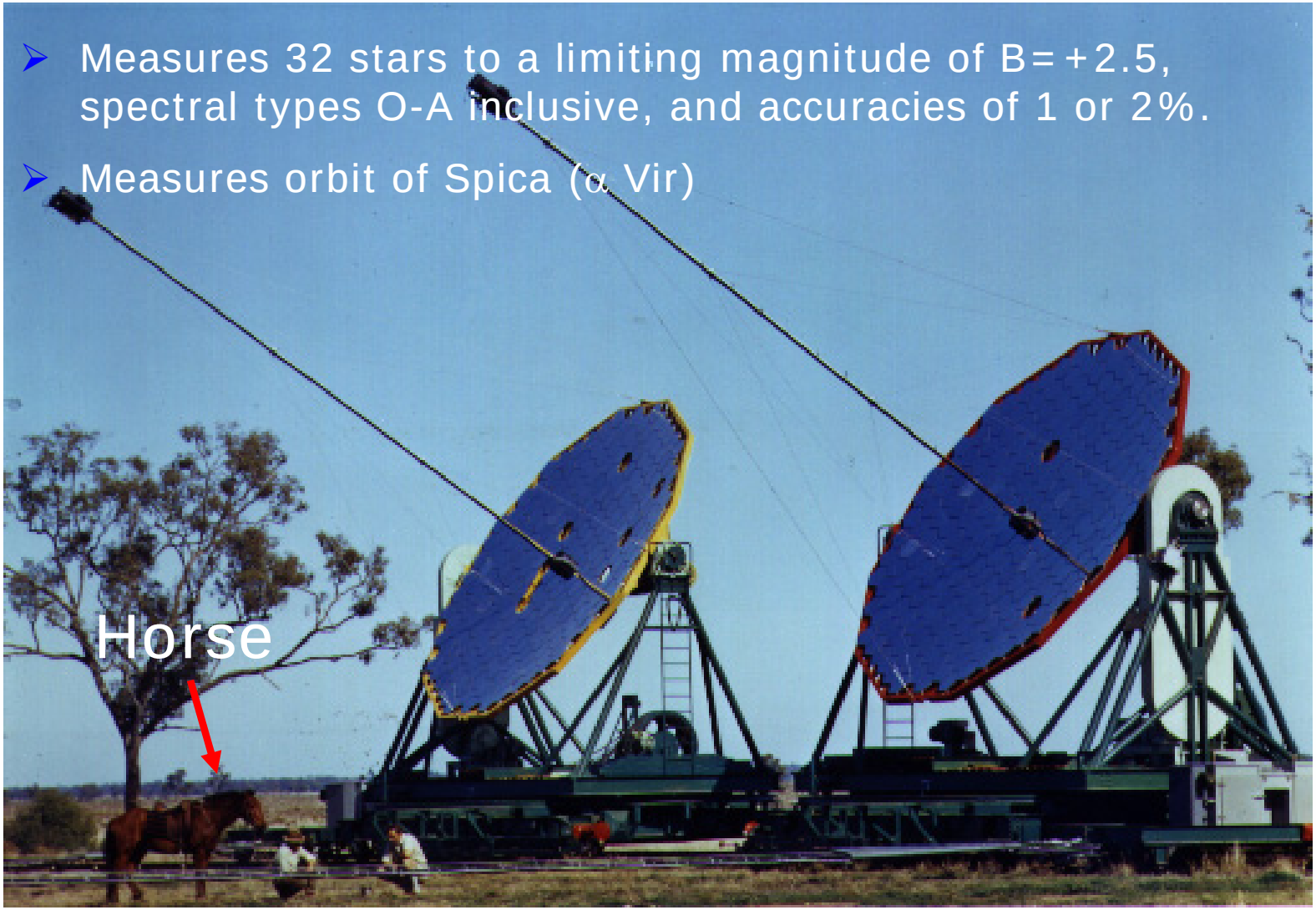
FIG. 7. The general layout of the interferometer at Narrabri Observatory.

Intensity Interferometer (1963-1976)

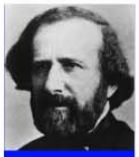


HISTORY of Stellar Interferometry

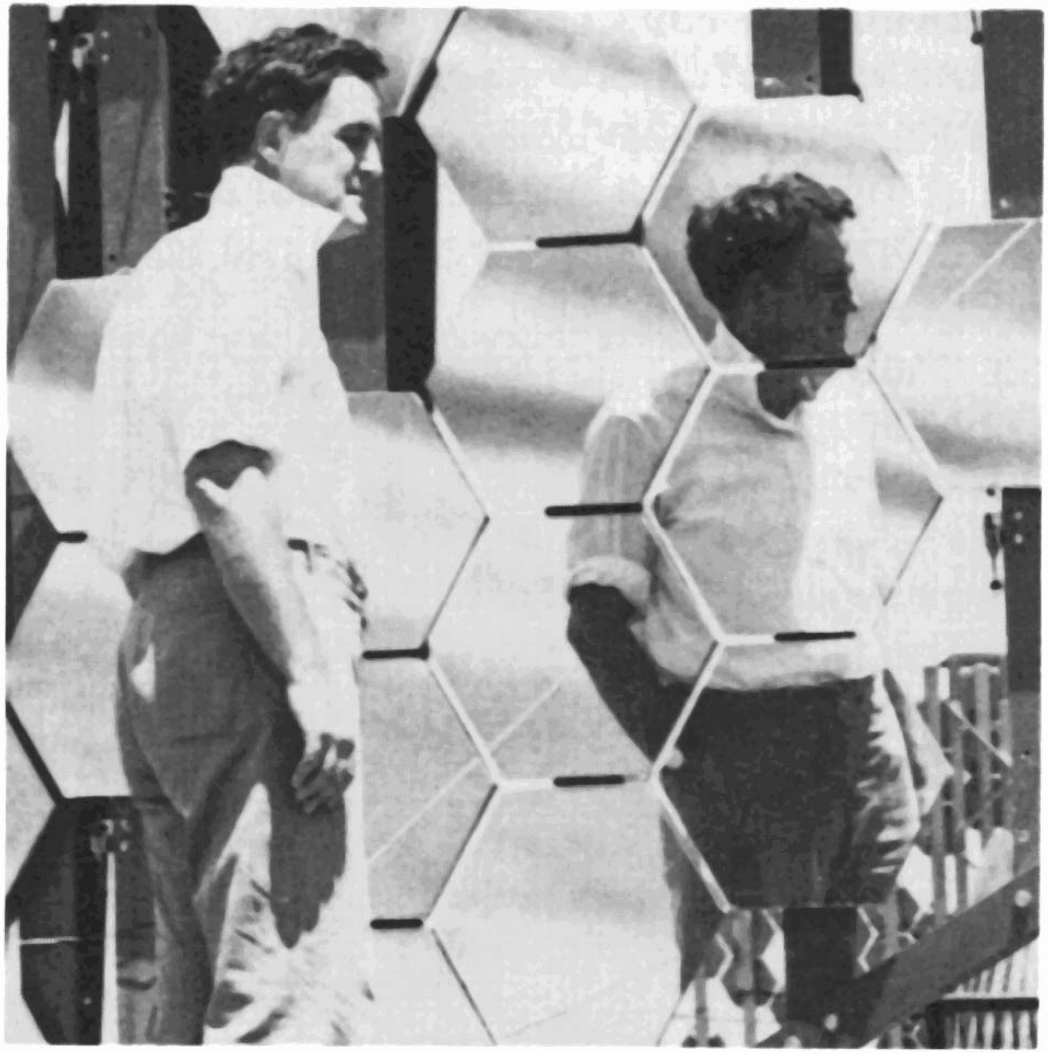
- Measures 32 stars to a limiting magnitude of B=+2.5, spectral types O-A inclusive, and accuracies of 1 or 2%.
- Measures orbit of Spica (α Vir)



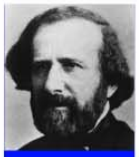
Robert Hanbury Brown



HISTORY of Stellar Interferometry



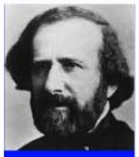
Interest in Optical Interferometry in the 1960s



HISTORY of Stellar Interferometry

- W.I. Beavers , “Modern Stellar Interferometry” ***Astron. J.*** 68 (1963)
- R.H. Miller, “Measurement of Stellar Diameters” ***Science*** 153 (1966)
- 1967 Woods Hole Summer Study on *Synthetic Aperture Optics* - Advisory Committee to the Air Force Systems Command
  - Closure phase proposed by Rogstad for optical arrays
  - D. Currie and the University of Maryland (1967)
  - H.A. Gebbie, R.Q. Twiss, W.J. Tango and the Monteporzio Interferometer
  - Goodman proposes aperture masking imaging with closure phase information
- E.S. Kulagin, Pulkovo Observatory, measures Capella 1970

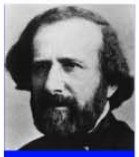
Interferometry in the Early 1970s



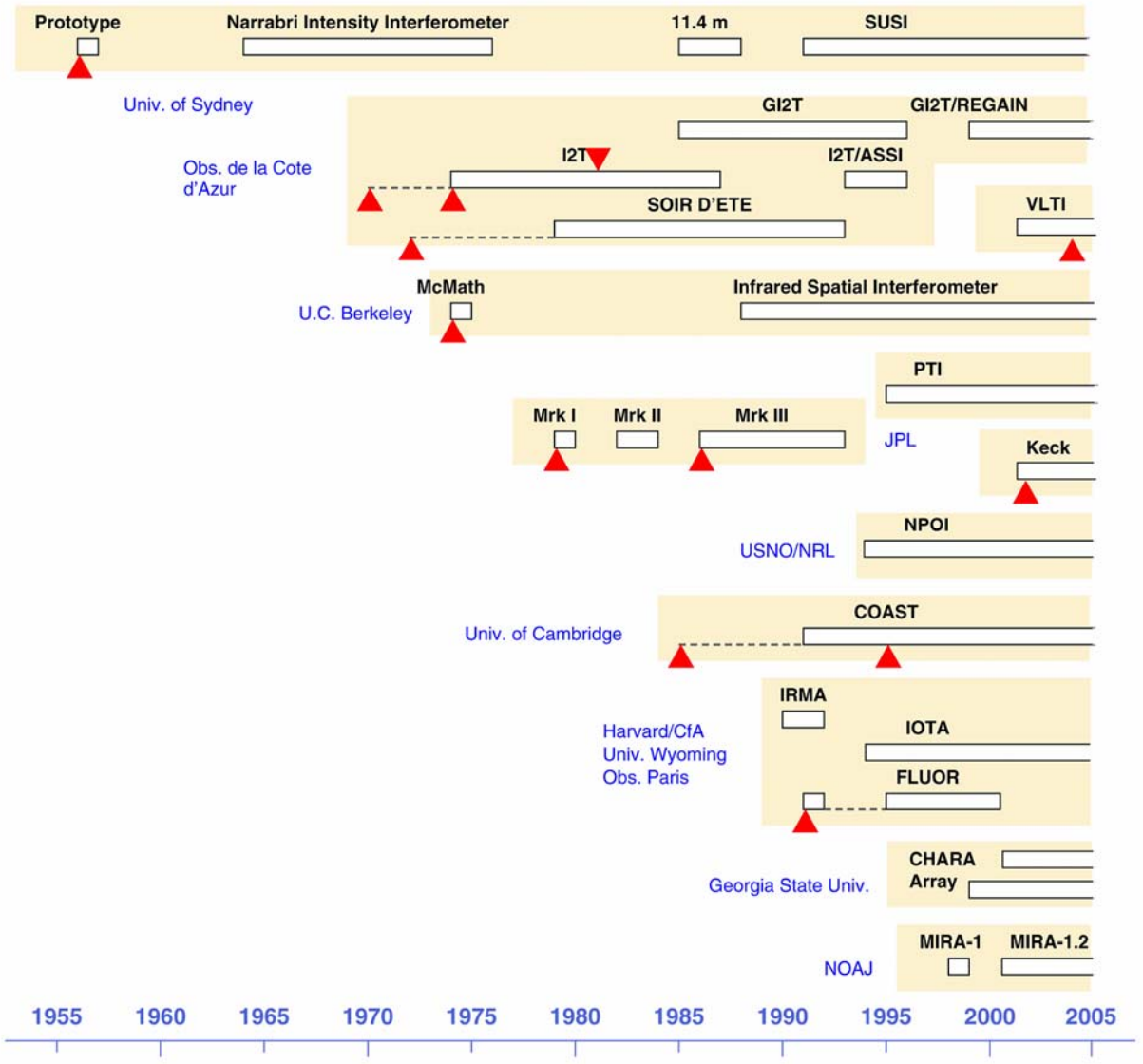
HISTORY of Stellar Interferometry

- Speckle interferometry invented 1970
- Lunar occultation measurements ongoing
- 10 micron heterodyne demonstrated by J. Gay at the Observatoire de Paris 1972.
- “Amplitude Interferometer” (aperture masking) by Currie et al. June-December 1972
- First long-baseline observations at 10 microns by Johnson et al. (1974) at MacMath Solar Observatory using the planet Mercury
  - Observations in late July and Early August 1974

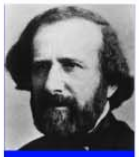
A New Frontier is Opened up in 1974



HISTORY of Stellar Interferometry

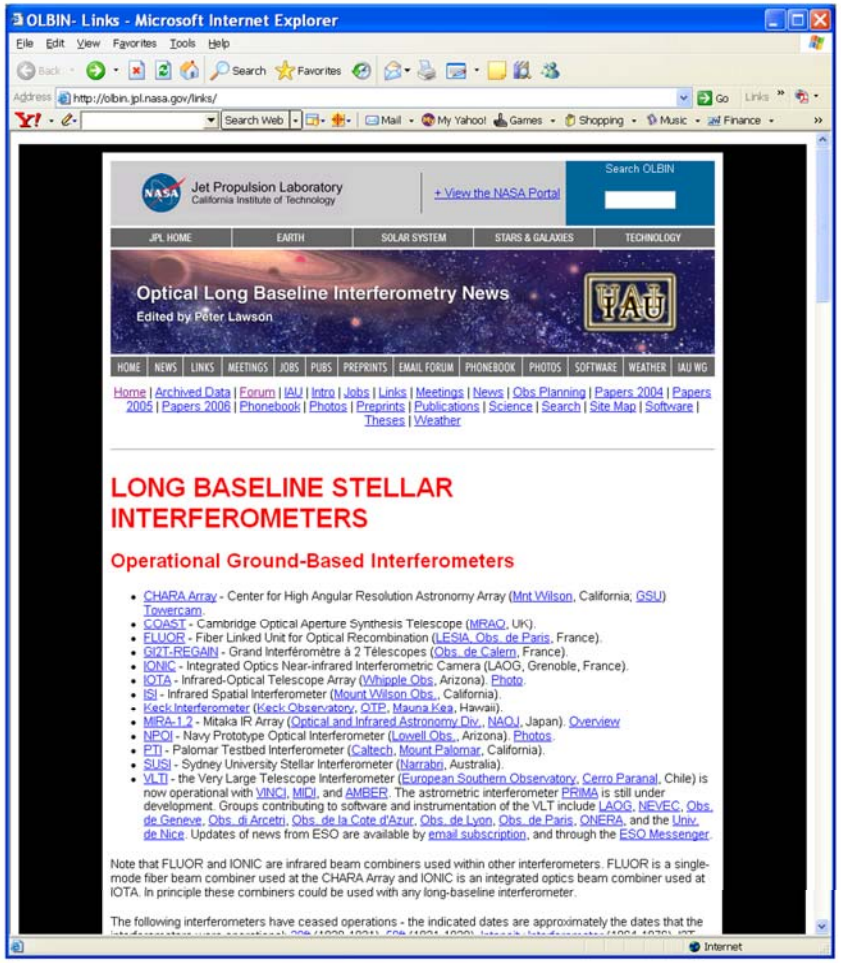


Acknowledgments



HISTORY of Stellar Interferometry

- Work by PRL was conducted at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.



- http://olbin.jpl.nasa.gov/